Brief Communication

A Ring Stabilizer for Lean Premixed Turbulent Flames

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INTRODUCTION

The Bunsen type conical flame is a classic configuration for fundamental combustion research. However, these flames, if stabilized by the burner rim, are unstable and blow-off easily under fuel-lean and high flowrate conditions. Although the use of a pilot flame can extend the operating range, in many cases the emissions from the pilot alter the overall flame emissions and can hinder research on ultra-lean premixed combustion systems [1].

In previous experiments on conical flame behavior in microgravity, which were conducted in drop-towers and in airplanes [2–4], the use of a pilot flame was not an option. To permit combustion of stable lean premixed conical flames without a pilot, a "ring stabilizer" was developed. Although similar types of bluff-body stabilization have been used in the past [5, 6], the ring stabilizer is somewhat unique. It is designed to fit inside the burner exit port and has demonstrated to be highly effective in stabilizing flames over a very wide range of conditions (including ultra-lean flames at high flowrates) without adversely affecting flame emissions. Unlike a simple rod stabilizer or a stagnation flame system, the benefit of having the stabilizer conform to the burner port is that there is very little leakage of the unburned fuel.

The purpose of this brief communication is to offer this simple and highly useful device to the combustion research community. Presented are highlights of a parametric study that measured the stabilization limits and pollutant emissions of several different rings, and demonstrated their potential for use in practical systems [7]. As mentioned, the usefulness of the ring stabilizer has already been exploited in a study that addressed the interactions between laminar flames and buoyancy [2–4].

RING STABILIZER GEOMETRIES AND EXPERIMENTAL METHODOLOGY

The ring stabilizers were mounted flush with the burner exit port and held centered in the flow field by three very small spindles (Fig. 1). The outer diameters of the rings were smaller than the inner diameter of the burner, thus leaving varying "gap sizes" (δ) which are defined as in Fig. 1. For the five rings discussed here (G0 to G4), δ varied from 0.0 to 3.2 mm in 0.8-mm increments. Each of these rings had 2×2 mm square cross sections. Other configurations were investigated, and the results were consistent with Cheng [8] that smaller dimension obstructions had better blowoff characteristics. Due to mechanical limitations, rings smaller than 2×2 mm were not extensively investigated.

Flows of natural gas (93.7% CH_4, 2.9% N_2, 2.5% C_2H_6, 0.9% CO_2) and air were metered, mixed, and inputted into the bottom of a burner. After passing through a settling chamber, the reactant flow was accelerated through a contraction section, through an optional turbulence plate, and out through a nozzle where the "ring stabilizers" were mounted. The diameter of the burner exit nozzle was 32 mm and the burner Reynolds number (based on the exit

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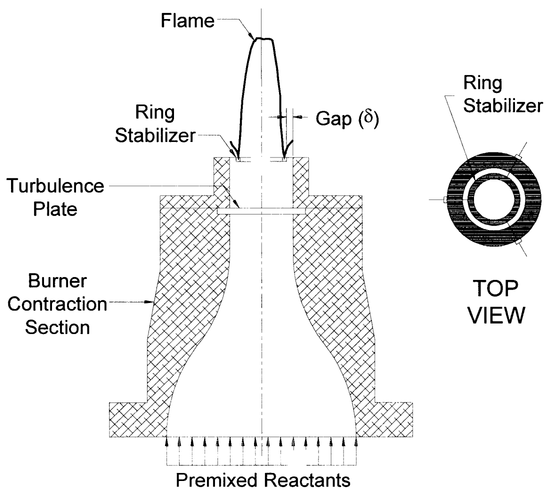

Fig. 1. Contraction section and nozzle of experimental burner.

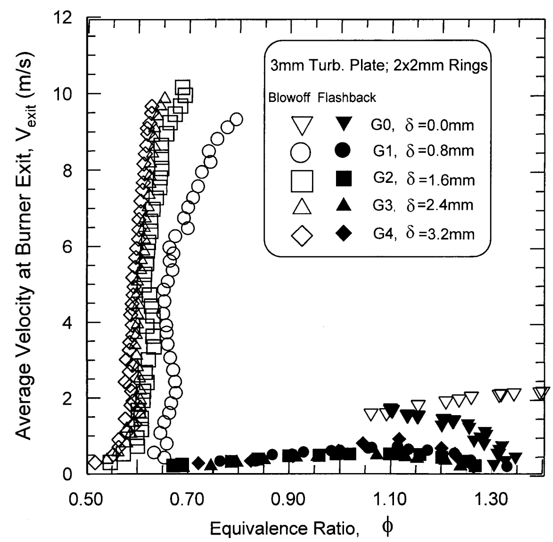

Fig. 3. Effect of ring gap size (δ) on stability of ring flames in turbulent flow.

diameter) varied between 700 and 18,000. Two different perforated plates with 2-mm and 3-mm holes and 50% blockage ratios were used to induce turbulence in the flow. The respective turbulence intensities at the burner exit were approximately 8% and 11.5% of the mean flow velocity.

RESULTS AND DISCUSSION

As shown in Fig. 2, the stability regime for the ring stabilized burner (ring G4, δ = 03.2 mm) is significantly larger than that for the standard rim stabilized burner. While both the blowoff and flashback limits were improved, the extension of the blowoff limits with the ring stabilizer was particularly dramatic. In the laminar case, ring G4 lean flames with equivalence ratios (ϕ) below 0.6 were stabilized. Possibly the most interesting result was seen in the relative effects of turbulence on the ring and rim stabilized flames. With the introduction of turbulence, the stability regime of the rim stabilized burner decreased dramatically. However, the effect of added turbulence on the stability regime of the ring stabilized burner was almost negligible. Additional stability data with lower intensity turbulence from a plate perforated with 2-mm holes (not shown) fell between the laminar and 3-mm turbulence plate curves for both the ring and rim stabilized burners. In short, the standard rim stabilized Bunsen type flame is not stable under fuel-lean operating conditions in turbulent flow. However, with the use of the ring stabilizer, stable combustion of ultra-lean turbulent flames is possible. Although effects of burner size have not been formally investigated, similar improved stability regimes were achieved on a 64-mm burner using rings with δ = 1.6 mm.

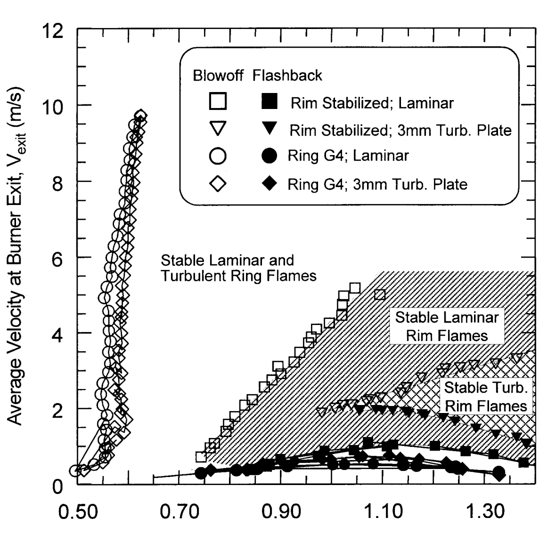

Fig. 2. Effect of turbulence on the stability regimes of ring and rim stabilized conical flames.

Figure 3 shows the influence of the ring gap size (δ) on the flame stability limits in turbulent flow. Increasing the gap size resulted in a modest improvement in the blowoff stability limit. Although there was a notable reduction in ϕ_{blowoff} as δ was increased from 0.8 to 1.6 mm, further reduction in ϕ_{blowoff} as δ was increased from 2.4 to 3.2 mm was much less obvious. For completion, the stability of flames on a ring with $\delta = 0$ mm (ring G0) was tested. As expected, with no gap and consequently no stable recirculation zone in the wake of the ring, the resultant flame essentially reverted to being rim stabilized and exhibited stability limits similar to those of the Bunsen flame in turbulent flow (Fig. 2). The transition between these two modes of stability was not investigated further because of the difficulty in machining and aligning rings with $\delta < 0.8$ mm. For the four rings with $\delta > 0$, the flash back limits were unaffected by the ring gap size.

Although it might appear that δ could be arbitrarily maximized to give optimum stability in all cases, further tests have shown that increasing δ can result in a corresponding increase in unburned hydrocarbon emissions (UHC) coupled with an increase in CO emissions. This increase occurs because the part of the flame that extends over the gap is unable to completely burn the reactants. It allows unburned reactants to mix with ambient air to an equivalence ratio below the flammability range. One would expect rod stabilized premixed V-flames to have relatively significant emissions of fuel and CO due to a similar dilution situation. For the test burner, with ring G1 ($\delta = 0.8$ mm), it was found that stable lean flame combustion was easily achievable without adversely affecting UHC and CO emissions. As expected, NO_x emissions were unaffected by increased δ, and decreased dramatically with decreased ϕ to approximately 0.071 g/kg fuel (2.1 ppm @ 3% O_2) of NO_x at $\phi = 0.65$. Thus, where stability is paramount, a larger gap size ring could be used to give maximum stability. However, where reduced UHC and CO emissions are also important, some optimization may be required.

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